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PRELIMINARY ASSESSMENT OF RFI IMPACTS ON TDRSS IN THE 2- TO 2.3-GHz BAND

J. D. Lyttle

10 May 1974

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2106.4 BAND AT EDGE OF DISTRIBUTION

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Technical Memorandum
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10 May 1974

PRELIMINARY ASSESSMENT OF RFI IMPACTS ON TDRSS IN THE 2- TO 2.3-GHz BAND

J. D. Lyttle

Interim Report No. 2
Prepared Under Contract No. NAS5-20406

This Document Consists of 39 Pages

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PRELIMINARY ASSESSMENT OF RFI IMPACTS ON TDRSS IN THE 2-TO 2.3-GHz BAND

1. INTRODUCTION.

The general objectives of this contract are:

a. To update and expand radio-frequency interference (RFI) environment models already existing at ESL, primarily from various documentary data sources.

b. From this data base, to evaluate RFI densities likely to impact on tentatively selected RF bands for Tracking and Data Relay Satellite System (TDRSS) including the relayed forward links (essentially commands) to user satellites and return links (telemetry) from user satellites.

c. To develop and present convenient geographic mapping of critical RFI evaluations.

The overall system model employed includes geosynchronous TDRSS in orbit to track and relay data to and from so called *user* satellites with various missions, exemplified by 500-, 1000-, 1500-, and 3000-kilometer (km) altitude circular orbits.

1. -- Continued.

Originally ten tentative radio-frequency (RF) bands were identified to be investigated for potential TDRSS use related to RFI impacts in these bands. Early in the project, responding to new guidance from the NASA contract Technical Officer, quick-look evaluations were performed on RFI conditions in the VHF 136-to 138-MHz and the UHF 400.5-to 401.5-MHz bands. The likely RFI problems reported from this preliminary investigation contributed to a shift of investigation for the TDRSS Program to the nominally 2-to 2.3-GHz band.*

This interim report provides, in the following section, an approximate chronological account of the investigations performed under this contract and some of the intermediate findings. Section 3, summarizes the preliminary results of RFI evaluations in the nominally 2-to 2.3-GHz band. Related to this, Section 4 contains an analysis of the time interaction of user satellites with microwave radio-relay type communications beams as a source of RFI.

*Part of the RF spectrum was formerly known as "S Band" (1.55 to 5.2 GHz) but is now identified as "E Band" (2 to 3 GHz) by the U.S. Department of Defense.

2. CHRONOLOGY OF PROJECT EFFORTS.

2.1 Quick-Look VHF/UHF Band Investigation.

Soon after the contract was started, on 12 December 1972, the cognizant NASA Technical Officer advised ESL of accelerated needs for RFI evaluations in the 136- to 138- and 400.5- to 401.5-MHz subbands. To meet this need, much of the planned, more-methodical updating and expansion of the Descrete Emitter Listing (DEL) data base was bypassed and available data on these two subbands was drawn together immediately, primarily from International Telecommunications Union (ITU) registration listings, to make the preliminary RFI evaluations. The urgency in the TDRSS Program for performing RFI analyses was understood; however, it should be recognized that quick response was emphasized over two more thorough and exact data accumulation and evaluation as originally planned in the contract. This accelerated effort resulted in certain numerical evaluations and general conclusions which were presented in a briefing/conference at Goddard Space Flight Center, Greenbelt, Maryland, on 16 February 1973. An interim report[1] was published soon after this meeting.

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[1] J. Jenny and J. Lyttle, *The Effect of Radio Frequency Interference on the 136- to 138-MHz Return Link and 400.5- to 401.5-MHz Forward Link of the Tracking and Data Relay Satellite System*, 1 March 1973, Technical Memorandum No. ESL-TM362 (Interim Report No. 1 under contract NAS 5-20406).

2.2 Initial 2- to 2.3-GHz Band Investigation.

In consonance with the TDRSS Program shift-of-interest to the usage of S-band (E-band) links, indicated at the 16 February meeting, a data survey was commenced for an analysis of potential RFI sources in the nominally 2- to 2.3-GHz band (specifically the 2025- to 2120- and 2200- to 2300-MHz subbands). Emitter data uncovered was reported in Project MAP Memos 3 and 4; the latter is recapitulated in Appendix A. The evaluation of this RFI was continued to a limited degree from various data sources available at ESL. As will be discussed in the following sections of this report, RFI from foreign radars appears to be dominant in this band. Specific data to support this evaluation was requested in Project MAP Memos 1, 5, 6, 7 and 8.

2.3 Emitter Data Base Expansion.

The general RFI data base has been updated and extended as planned using several sources. From direct acquisition by ESL from ITU, Geneva, applicable data has been incorporated from registrations in the International Frequency List. Basic reduction of data from this source was completed and covers the ten RF bands of original interest for TDRSS application.

In response to a specific data request from the NASA Technical Officer, the Electromagnetic Compatability Analysis Center, Annapolis, Maryland, processed and delivered to ESL three magnetic tapes containing listings of *equipments* they recognized as operating in and near the RF subbands of interest.

2.3 -- Continued.

These Univac-computer format tapes could not be read immediately with conversion software used with previous ECAC tapes two years ago. After obtaining additional format and coding key tables from ECAC, and interfacing directly with their staff (notably Mr. Frank Reynolds), the format problems were resolved and, by April 1974, these tapes were successfully translated into a convenient IBM-computer format for further technical processing. The ECAC tapes were not received and processed in time to impact on the VHF/UHF quick-look evaluations. However, these additional data indicated additional justification that RFI in these bands would produce serious inhibitions to efficient TDRSS operation. The ECAC data have been used to evaluate the 2- to 2.3-GHz band RFI sources, principally among point-to-point communications in North America.

2.4 Mobile/Sporadic Emitter Modeling.

Modifications were also made to certain ESL computer programs that have been used to evaluate RFI conditions. These improvements facilitate RFI modeling of mobile and/or sporadic transmission emitters using probablistic controls. One routine permits the creation of new discrete emitter listing (DEL) entries with pseudo-random distributions within given (1) radio frequency and/or (2) geographic location bounds. The emitter quantities chosen for such a DEL data set could be an estimate of the

2.4 -- Continued.

number of a particular type of emitters that would be transmitting simultaneously. Multiple data sets could be created for different levels of emitter activity and/or similar sets created with different random distributions for Monte-Carlo type analysis of these effects.

Another new software routine permits pseudo-random sifting of already available DEL data sets, within given frequency and location bounds, according to a desired percentage of these emitters to be active simultaneously. Likewise, multiple sifts can be made for Monte-Carlo analysis.

The majority of RF sources in the UHF and microwave bands (except for television and some navigation aids) operate on sporadic schedules; and many are mobile as well. Descriptive information available on such emitters does not provide precise operating schedules and often, gives only frequency bands and broad geographic areas of use instead of specifics. The new software routines permit the creation of multiple DEL sample sets to more realistically model the largely stochastic nature of these types of RFI environments.

2.5 Task III Modification.

The originally defined Task III of this contract called for a specific investigation of emitter conditions in the 121.6- to 121.9-MHz band. When the TDRSS Program RF-links application

2.5 -- Continued.

was focused on the 2- to 2.3-GHz band, this specific VHF subband investigation was not needed. Although we had already updated our RFI data base in this band early in the project, it was agreed to redirect the effort, at no cost differential, with a requested analysis of RFI data recorded on magnetic tapes by NASA sponsored monitors. After abstracting calibration from the tapes, these data were compared with the DEL RFI sources being evaluated under Task I. This analysis was accomplished and the results published within our Interim Report No. 1[1]. Therefore, Task III, as modified, was completed.

2.6 Futher 2- to 2.3-GHz Band Investigations.

While waiting for more substantive data to be acquired from another government agency on specific types of foreign emitters thought to be operated in the 2- to 2.3-GHz band, analysis was continued on this problem, based upon partial information already available at ESL. Preliminary recommendations for TDRSS frequency usage were provided in Project MAP Memo 7, on 14 July 1973, and recapitulated in the Monthly Progress Reports for June 1973 (ESL-4537, dated 17 July 1973), and for September 1973 (ESL-5038, dated 10 October 1973). This reaffirmed the appraisal that foreign radars would be the major RFI source in this band.

Two essentially geometric evaluations were performed at this time. One of these developed approximate zone limits of the major radar interference areas expected in the 2- to 2.3-GHz band, related to exemplary user-satellite orbit altitudes. The

2.6 -- Continued.

results of this preliminary analysis are presented in our September 1973 MPR and are given in more detail in Section 3.2 of this Interim Report.

The other geometric evaluation dealt with the problem of MCW signal interference from point-to-point communications and similar emitters, although, these still appear to represent a relatively much less significant RFI problem than do radars in this band. A measure of the time that user satellites (at exemplary orbit altitudes) could be in the main beam of radio-relay communications-type transmitters was investigated. These results are presented in Section 4.

2.7 Advisory Conference.

On 11 October 1973 a conference was held with the NASA Technical Officer and a representative of the TDRSS Program Office at Goddard Space Flight Center. Progress and significant results of this project, since the February conference, were reviewed - stressing the preliminary conclusions drawn about potential radar interference that are summarized in Section 3.

This important interchange with TDRSS Program Office reaffirmed the technical guidance which terminated requirements for further investigation of RFI effects in the VHF (notably 136 to 138 MHz) and UHF (400.5 to 401.5 MHz) bands and concentrated

2.7 -- Continued.

continued analysis in the 2- to 2.3-GHz band. Pertinent new planning information on potential TDRSS communication usage and other technical data were provided to ESL at that time.

Unfortunately, it was found that follow-up on the requests for particular technical data on foreign radars, etc., had lapsed, because of Government reorganizations, in mid 1973. Therefore, also on 11 October, liasion was reestablished and an appropriate new administrative request was drafted for the data needed. There was encouragement that the information could be provided to ESL to continue the planned RFI evaluations.

2.8 Contract Extension.

Nevertheless, the delay in this project, incurred while waiting for these input data, made it impossible to complete the planned work within the originally scheduled one-year time period, ending 11 December 1973. Even though an expanded schedule would not make as efficient use of contract funds, it was estimated that the required work could still be performed within the originally proposed cost budget but spread over a greater time period. Therefore, an extension of time for performance of this contract was officially requested, at no additional cost to the Government, to allow for receipt of the input data, analysis of these important factors, and publication of the findings.[2]

---

[2]Letter to NASA-GSFC (244), *Time extension under contract no. NAS5-20406*, 14 December 1973, ESL-5368.

2.9 Space Shuttle RFI Investigation.

In early October, a letter was received from the Technical Officer[3] that forwarded a request to ESL for an RFI appraisal related to the Space Shuttle Program[4]. Since frequencies to be used with this program are also planned in the 2- to 2.3-GHz band, it appeared that these considerations could be included along with the analyses for the TDRSS Program under this contract. Only general conclusions could be drawn and offered at this time[5], similar to those for TDRSS, pending receipt of the more detailed data on radar and other RFI sources likely to be in this band.

2.10 Preliminary 13 to 16 GHz Investigation.

ESL commenced surveying and cataloging types of emitters that have been identified in the other planned TDRSS bands between nominally 13 and 16 GHz.* It was immediately apparent that the likely RFI impacts in this high microwave band should

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[3] Forwarding letter and guidance from John W. Bryan, NASA, Goddard Space Flight Center, File 4399, 21 September 1973, for letter below.

[4] Letter which marked radio frequency interference at "S band" from Sidney W. Novosad, NASA, Lyndon B. Johnson Space Center, EJ5-73-295, 29 August 1973.

[5] Letter "Radio Frequency Interference Analysis for Space Shuttle", ESL-5457, 8 January 1974.

*This part of the RF spectrum was formerly known as "K_e band" (13.25 to 14.25 GHz) and "K_c band" (14.24 to 15.35 GHz) but is now identified as a portion of "J band" (10 to 20 GHz) by the U.S. Department of Defense.

2.10 -- Continued.

not be nearly as troublesome as the utilization in the 2- to 2.3-GHz band, for the following general reasons (applicable to the nominally 13- to 16-GHz band):

a. Typical power levels of transmitters are comparatively low, primarily because of the greater difficulty of designing high-power amplifiers with the small dimensions required at these wavelengths.

b. Until recently, with the growth of communications satellite system applications, the RF usage was dominated by airborne radars of various kinds (usually for military applications, that require operation only, sporadically and infrequently).

c. The great majority of equipment applications take advantage of the facility to form very narrow, directive, and usually rapid-steering beams, using relatively small antenna apertures; therefore, the statistical likelihood of being within such a main-beam radiation pattern is low and brief.

d. A major application for airborne radars in this band is in navigation systems (like altimeter and doppler radars) which direct their radiation patterns essentially downward from the aircraft and, thus, would be a much reduced source of RFI to satellite links.

2.11 New Data on 2 to 2.3 GHz Foreign RFI Sources.

On 21 January 1974 ESL received a set of classified material from NSACSS, essentially in response to the data rerequested at to NASA/GSFC on 11 October 1973. Although the material did not fulfill the intended request completely, it is providing substantial factual information on which to base continued analysis of potential RFI sources in the nominally 2- to 2.3-GHz band, which may impact on TDRSS operations. Based on previous evaluations, the most important concern was to determine the extent of RF distribution (within this band) of radars as interference sources. The new data received does certainly allow better insight into this problem, even though the requested RF-usage "histograms" of the likely offenders were not provided.

Within a few days of receipt of these new data, the major impacts were analyzed and the quick-look results reported to the NASA/GSFC Technical Officer (Code 591)[6], modifying slightly the previous general guidance provided for the TDRSS Program.

ESL continued to analyze the new data with the primary object to more specifically define additional inputs needed to access foreign RFI impact in this band. This resulted in a more detailed request for data that was submitted 22 February directly by ESL to the appropriate U.S. Government agency through the designated officer (Mr. John Bredbenner) for NASA liaison. In early April, most of the data requested, was received with a statement that additional material was forthcoming.

[6] Project MAP Memo 9 -- Preliminary Analysis of New RFI Source Data, ESL-5568, 31 January 1974.

2.11 -- Continued.

ESL is continuing to analyze these data on radar interference, as well as look for incidence of communications RFI sources although the latter are of less significance.

3. PRELIMINARY RESULTS OF 2 to 2.3 GHz RFI INVESTIGATION.

3.1 Status Summary.

Tasks I and II of this contract originally indicated that two of the bands to be investigated for the RFI were:

Links	Channels Within RF Bands 2025-2120 MHz	2200-2300 MHz
Earth to TDRS		Two 10-MHz
TDRS to Users	Four 10-MHz	
Users to TDRS		Four 10-MHz
TDRS to Earth	Four 10-MHz	

Preliminary investigations, starting in February 1973, indicated a certain amount of point-to-point communications usage in these bands, particularly in North America. A summary of preliminary evidence on these and other 2 to 2.3 GHz RFI sources is provided in Appendix A. However, it became apparent early in the investigation that a more significant source of RFI is likely to arise from military radars in this band; notably ones operated for various air-defense purposes by the USSR and some of their Warsaw Pact associates in Eastern Europe. Without performing explicit evaluations, it can be shown that any typical megawatt transmitter radar will produce significant pulse power levels at a TDRSS location, coupling through radar sidelobes (as well as its main beam) over a majority of random aspect angles. This radar interference problem continues to be investigated.

3.1 -- Continued.

In June 1973, more specific direction was given to the 2 to 2.3 GHz RFI investigation. Because of inhibitions from other space-program users, the RF bands of interest were reduced slightly, and an objective was given to operate two links at frequencies which are harmonically related at a specific ratio. One or more pairs of RF subbands, with minimum RFI, were sought which met, or approached, the following criteria:

(a) TDRS-to-User satellites command link of 2 to 3-MHz bandwidth between 2036 and 2110 MHz.

(b) User-to-TDRS Satellites telemetry link of 5-MHz bandwidth between 2200 and 2290 MHz.

(c) Optimally, the pair of link frequencies to be displaced by a ratio of 221:240.

Based on then incomplete technical data on certain radar RFI sources, preliminary recommendations were made of frequencies:

(1) If 221:240 RF ratio must be used, nominally 2070 and 2248 MHz should avoid much radar RFI.

(2) Less radar RFI should be encountered below about 2050 MHz and above about 2250 MHz.

3.1 -- Continued.

Examples:	RF Pairs (MHz)	Ratio
	2048 and 2252.80	10:11 (or 220:242)
	2038 and 2287.55	49:55

The more detailed data on foreign radar RF utilization received in January permitted a revision of this estimate:

(1) Essentially, frequencies (within the indicated bands of interests) below about 2067 MHz and above about 2239 MHz would not likely suffer radar interference.

(2) These bounds do, barely, permit use of the 221:240 frequency relationship. For example, two 5-MHz TDRSS operating bands could be centered at about 2064.5 and 2242 MHz.

3.2 Potential RFI Zones from Military Radars.

As indicated in Sections 2.6 and 3.1, the conclusion was drawn early that radars would produce the most significant RFI sources in the 2- to 2.3-GHz band; therefore, we sought to define areas of the earth (and space above it) that would probably include such radar transmissions. A number of radar types are apparently made and used in the USSR that operate in this RF band. More precise information is being obtained, as indicated in Section 2.11, that will permit assessment of RFI impacts on the TDRSS links of concern. In the meantime, it was determined

3.2 -- Continued.

that a deductive analysis and certain geometric evaluations could be performed to make preliminary estimates of the zones where this type of RFI is likely.

The great majority of radars in the world (in all countries) are used for some aspect of military air defense. Among these many air-defense radars, the largest number are intended to perform surveillance roles. The general term "surveillance" is used to include the functions sometimes called early warning, air search, air control and warning (AC&W), ground-controlled intercept (GCI), height finding, plus combinations of these and others. There are several significant general characteristics of surveillance radars that are important when considering them as potential RFI sources:

a. To perform their surveillance role (especially early warning), these radars must be operated virtually continuously (around the clock, every day). Logically, they are "off the air" only when equipment casualties occur and maintenance is being performed and/or when a relatively nearby radar(s) of similar capability is used to "cover" that air-defense sector.

b. To obtain their required long-range coverage, they must be relatively high powered; typically of the order of a megawatt or greater transmitter (peak pulse power).

3.2 -- Continued.

c. To obtain complete coverage in altitude, they usually have either wide vertical beamwidth (compared to narrow azimuth beamwidth), "stacked" multiple beams in the vertical plane, or rapid vertical beam-scanning motion.

d. To obtain complete coverage in azimuth, they usually are continuously scanned in azimuth; a 360° "circular" scan is most common but wide azimuth-sector scans are also used.

e. To provide the earliest detection, and response to an air attack, some of these radars are always located along, and particularly at, the extremity of a country's borders (using off-shore islands where available) except possibly in arctic areas where logistics support, etc., for radar out-stations is very difficult.

f. To ensure completeness of coverage and possibly backup redundancy, these radars are usually deployed with overlapping, sometimes extensively, coverage areas.

Because of the similarity of these characteristics among air-defense radars produced by all countries, it can be assumed that if such radars exist at all in the RF bands of interest for TDRSS, then they will probably produce a serious RFI problem.

3.2 -- Continued.

Furthermore, the latter two factors indicated above suggest that the exact location of such radars need not be known to obtain a first-order evaluation of their impact. Since they typically are deployed at least along the outer edge of a nation's "air defense perimeter," they are very likely to be quite near that country's physical and political boundaries.

From this deduction, contours can be constructed which indicate where satellites (in given orbits) will be within line-of-sight of the borders of certain countries or other defined areas. For TDRSS user satellites, this condition was evaluated for circular orbits of 500-, 1000-, 1500- and 3000-kilometer (km) altitudes. Primarily, the boundaries of the USSR were used, since this is thought to be the origin and prime user of radars in the nominally 2- to 2.3-GHz band.

Figure 3-1 shows the approximate zone limits of this RFI source; indicated by the loci of subpoints for the four stated circular-orbit altitudes. The shaded area in the Northern Hemisphere is where 500-km orbits will probably encounter radar RFI. The successive contour lines to the south indicate the larger limits for the three higher altitudes.

It is not yet determined whether Soviet radars in this RF band are also deployed in Eastern European countries (specifically, East Germany, Poland, Czechoslovakia, Hungary, Rumania and Bulgaria). However, if they are then these RFI zones would be extended, which is shown by the dashed lines in the vicinity of the Atlantic Ocean.

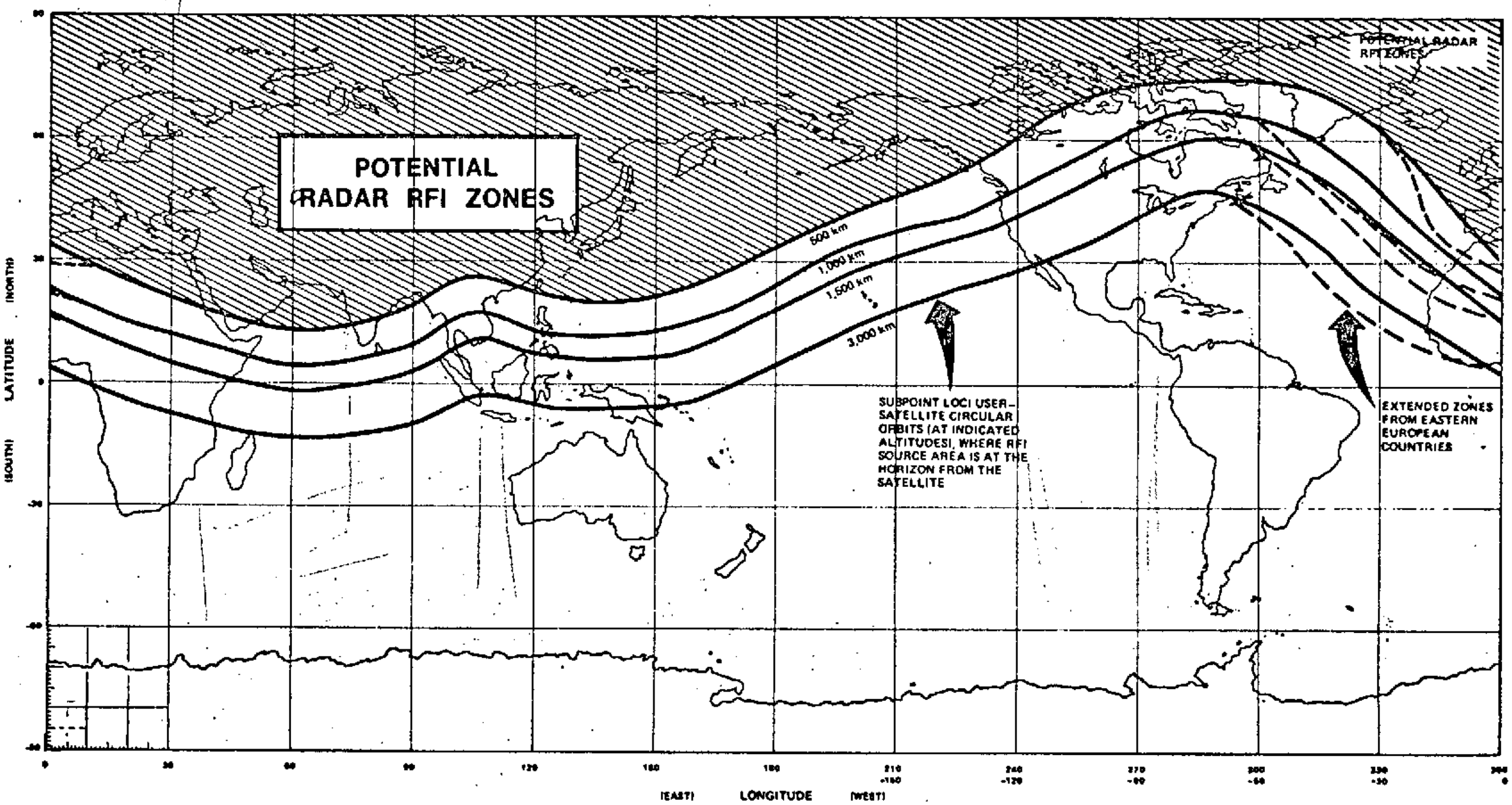

Figure 3-1. Approximate Zone Limits of Likely Radar RFI in the 2 to 2.3 GHz Band for Four User Satellite Circular Orbit Altitudes.

3.2 -- Continued.

It can be readily seen that virtually all of the Southern Hemisphere of the earth and most of the Western Hemisphere are outside of these RFI zones. Thus, TDRSS communications to user satellites could be performed when they were in this extensive area (volume) which is free of this source of radar RFI. Evaluation of the degree of RFI within the inhibition zones indicated is now the main effort of work on this contract.

For link receivers on TDRS spacecraft to avoid this source of radar RFI (geometrically from anywhere in the USSR), the geo-synchronous TDRS must be located between nominally 59° and 101°W longitude; assuming negligible eccentricity and inclination movement. If this type of radar RFI also could come from Eastern European countries, the TDRS location limits would be reduced to 67° to 101°W (using the western edge of East Germany as the furthest extremity). Since neither of these limits for TDRS location are satisfactory, compared to the desired 41° and 171°W (±10°), it must be assumed that the TDRS receiver links require a design to ameliorate the effect of radar RFI through either detailed frequency selection and/or appropriate communication "coding" that is tolerant to pulse type interference.

3.3 Preliminary TDRSS Guidance.

Several broad conclusions can be drawn now, even though considerable analysis is yet to be completed on the model of likely RFI to the TDRSS. The 2- to 2.3-GHz band, in general, is

3.3 -- Continued.

not the best choice from the standpoint of low RFI. Relatively however, it is better than almost any part of the VHF band and much of the lower UHF band. On the other hand, a number of higher microwave bands have much less likelihood of conflicting RFI. Nevertheless, it is recommended:

a. Design the TDRSS communication system with RF tuning flexibility within the 2 to 2.3 GHz to avoid present and future RFI "hot spots."

b. Use a signalling technique (or certain forms of communication coding) designed to be relatively tolerant to pulse form RFI (typical of radar signals), because that is likely to be the dominant type of RFI.

c. Time schedule communications to user satellites to avoid known geographic zones of RFI, similar to the preliminary diagram presented in Section 3.2.

4. TIME INTERACTION OF USER SATELLITES WITH MICROWAVE RADIO-RELAY COMMUNICATIONS RFI BEAMS.

Throughout the world, and particularly in North America, microwave radio-relay communication lines represent the most common type of radio-frequency (RF) emitters in the 2- to 2.3-GHz band; although they do not contribute the most high-power emissions. The transmitters of typical direct-path (not troposcatter) radio-relay sets operate with from one to five watts of power into their antenna system. These antennas are very high gain, within the practical limits of reflector aperture sizes to be mounted on often light-structured towers. A simple example is shown in Figure 4-1.

To reduce problems from mutual RFI within a given radio-relay line, these antennas are designed with low side and back lobes. Therefore, it is the radiation in their "main beam" which constitutes by far the most significant source of RFI to other systems such as satellite communications.

Radio-relay antennas are positioned with precision to point at another receiving transmitting antenna on the next tower in the line. Thus, the main beam is orientated almost horizontally, with a few exceptions, for example, where a tower is on a high mountain communicating directly with an adjacent site in a low valley.

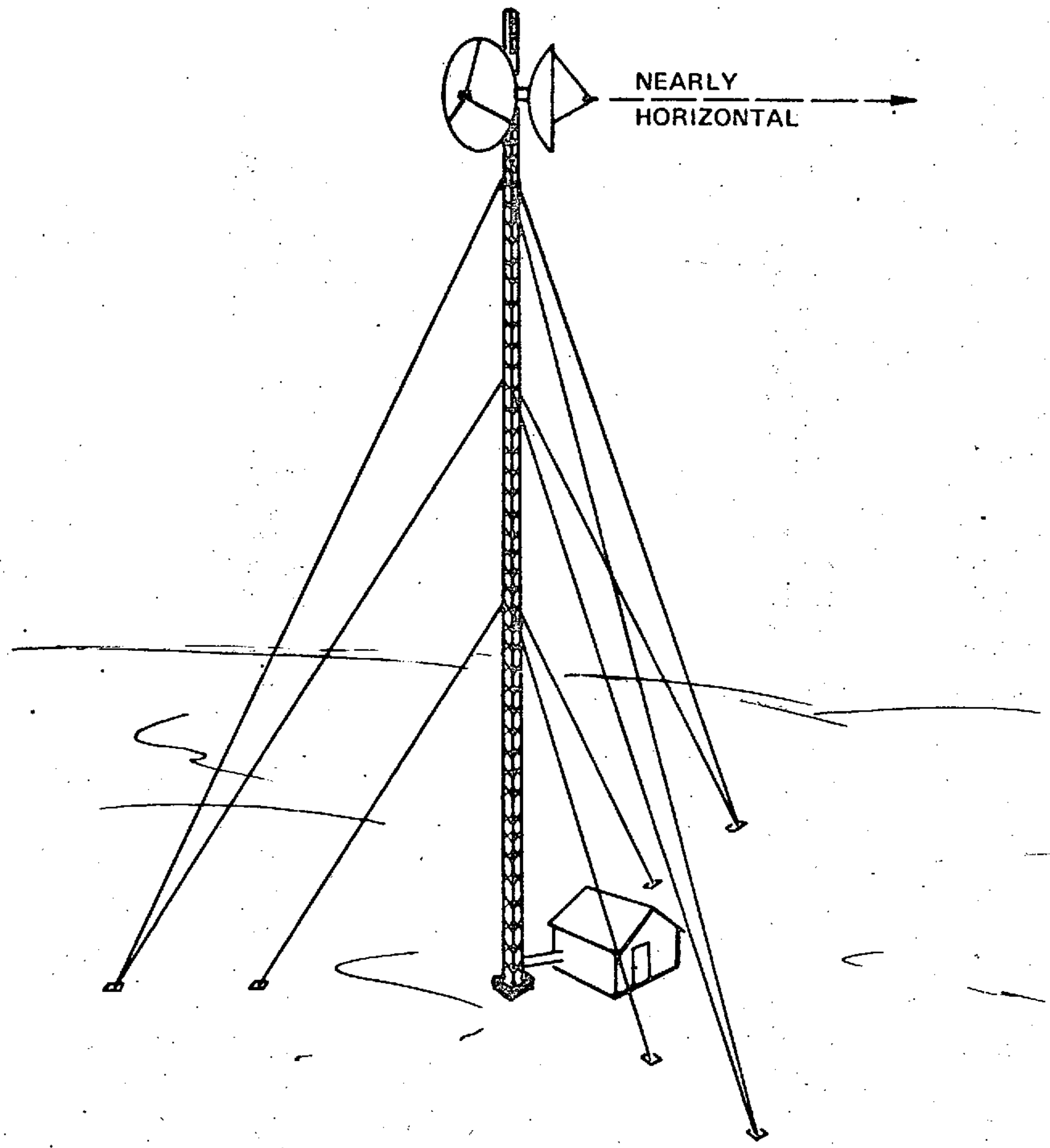

Figure 4-1. Typical Microwave Radio Relay Antenna Mounting

4. -- Continued.

The interaction of these radio-relay beams with orbiting satellites around the earth is geometically complex. To visualize the problem, an earth satellite vehicle in a essentially circular orbit may be regarded as remaining on an imaginary sphere around the earth at the altitude of this orbit. Figure 4-2 illustrates this with a random selection of orbit revolutions, relative to fixed locations on the earth. Figure 4-3 shows a schematic relay beam and the resulting elliptical intersection with the satellite orbit "sphere." Depending upon both the azimuth orientation of the radio-relay beam and the inclination of the satellite orbit, individual satellite "passes" (revolutions) may cross through this beam in an infinite variety of orientations. A few examples are shown in Figure 4-4. The maximum intersection length would be for an orbit pass essentially in the plane of the radio-relay beam horizontal axis (the major axis of the elipsoid intersection).

Each radio-relay beam is fixed relative to the earth. However, the earth rotation imparts motion to this beam in space. Since we are primarily interested in the time that a satellite would be within such a radio-relay beam, the earth-rotation motion of the beam and the satellite vector must be

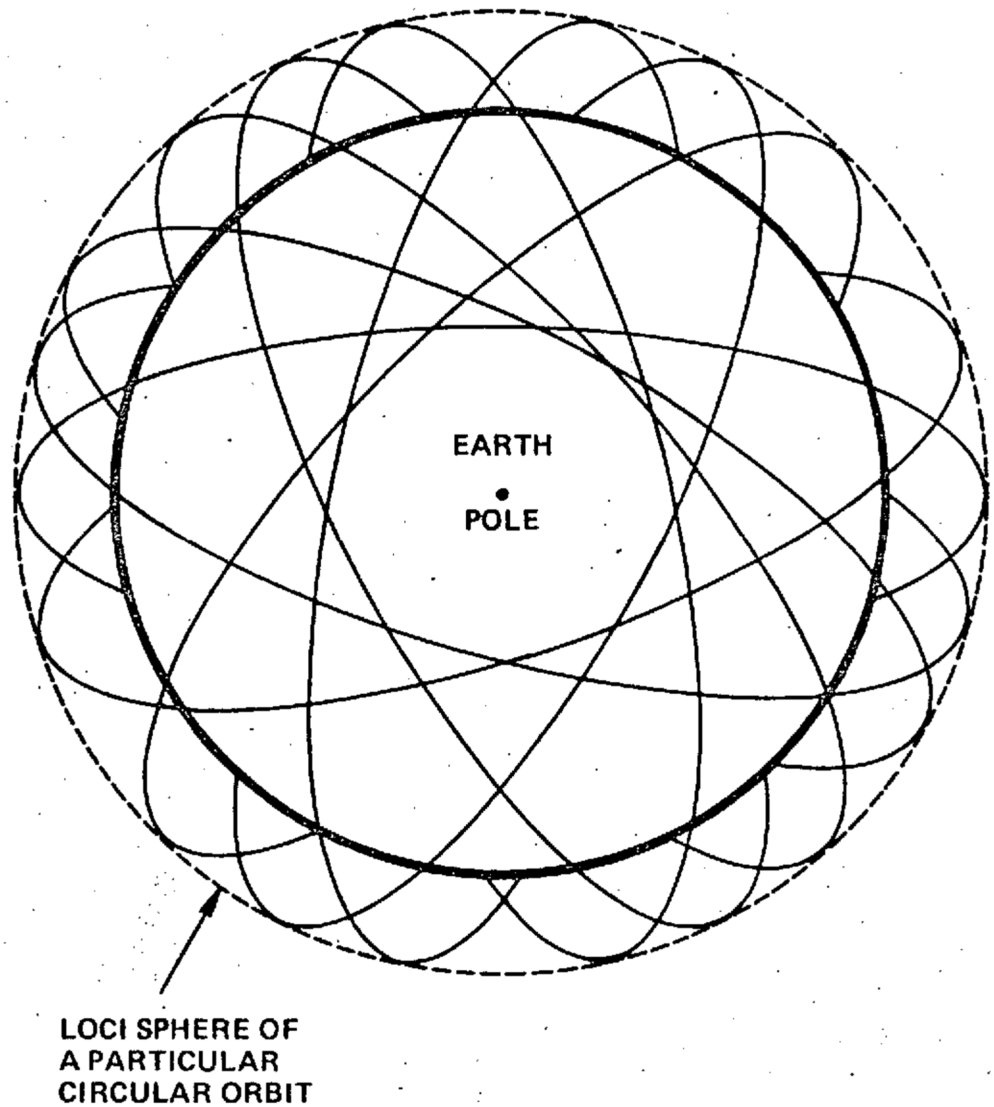

Figure 4-2. Spheroid Containing Revolutions of a Particular Circular Orbit

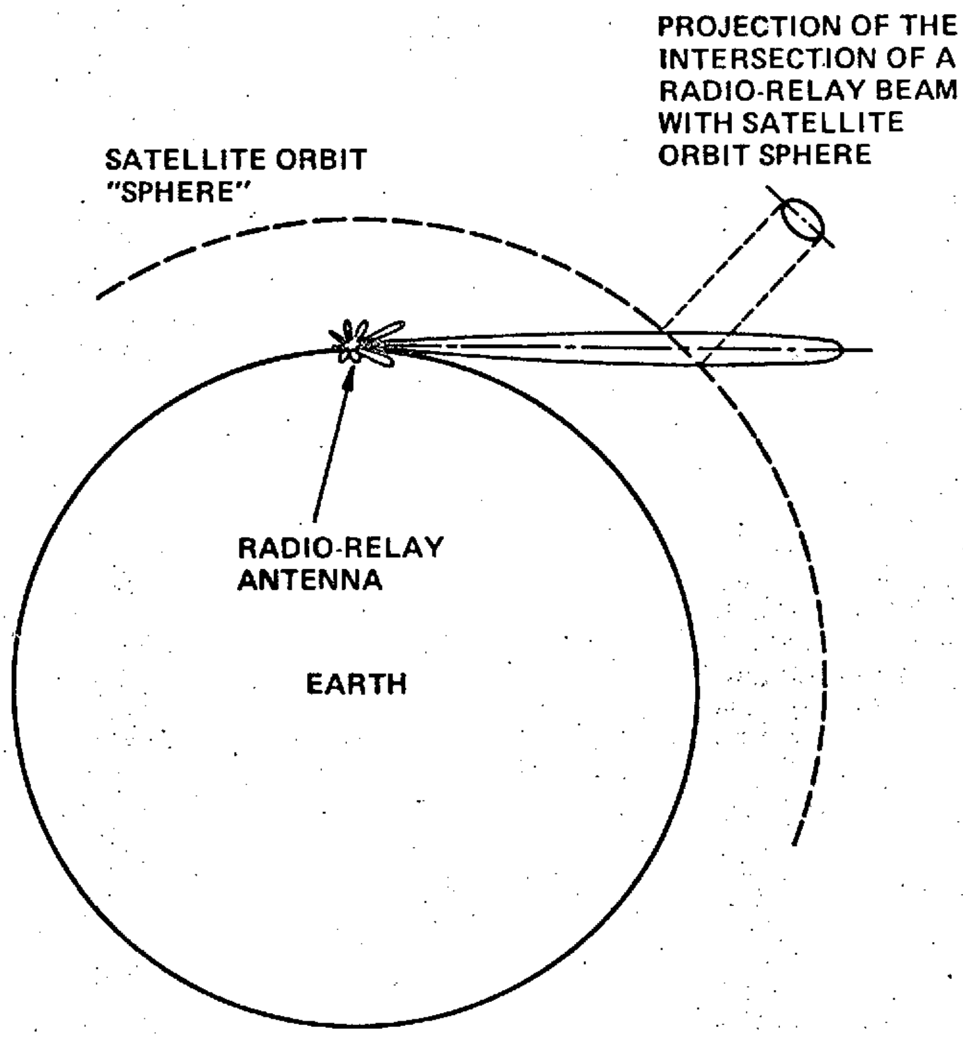

Figure 4-3. Intersection of Radio Relay Beams With Satellite Orbit Spheroid

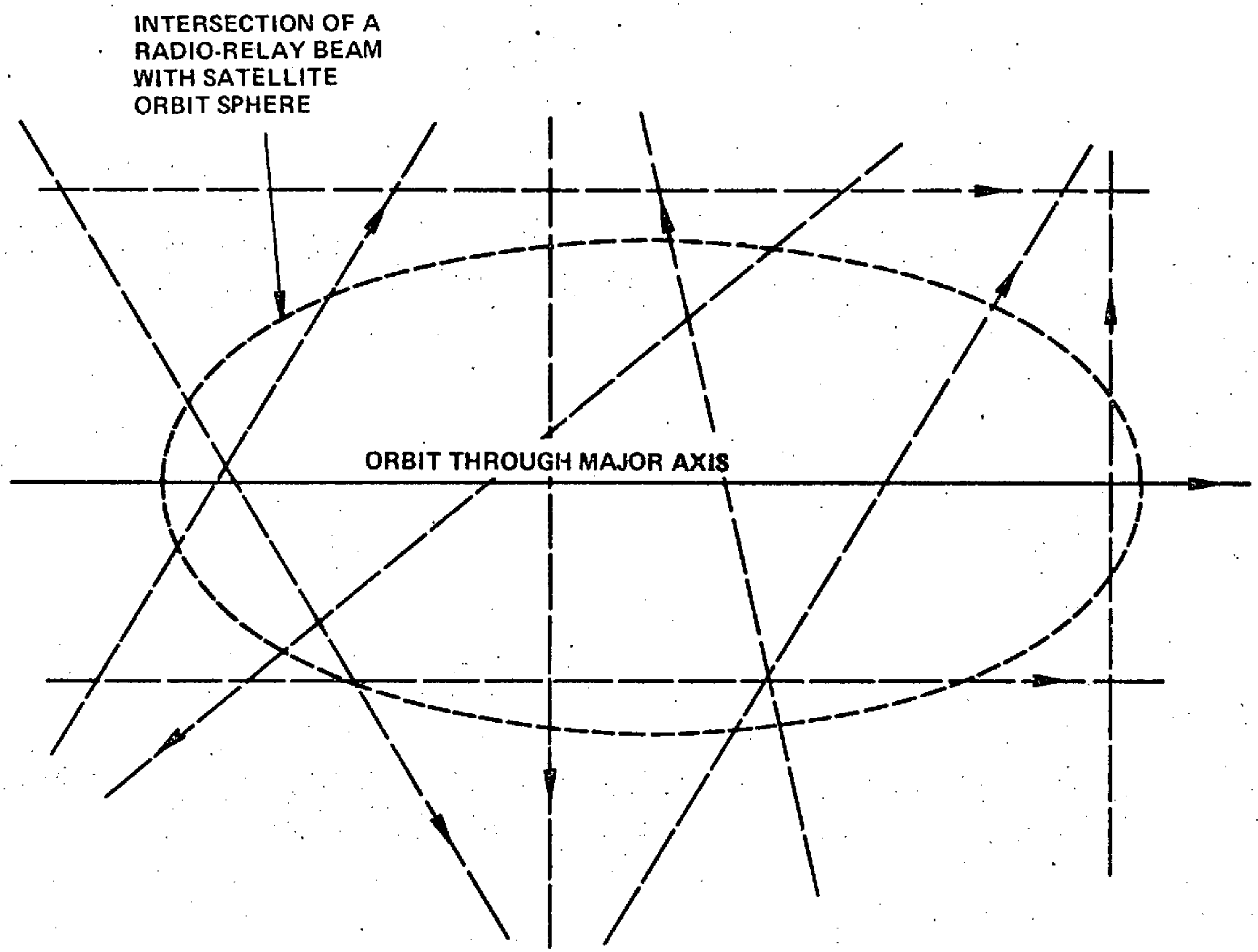

Figure 4-4. Examples of the Infinite Variety of Intersections of Orbit Revolutions With Radio-Relay Beams on Different Azimuths

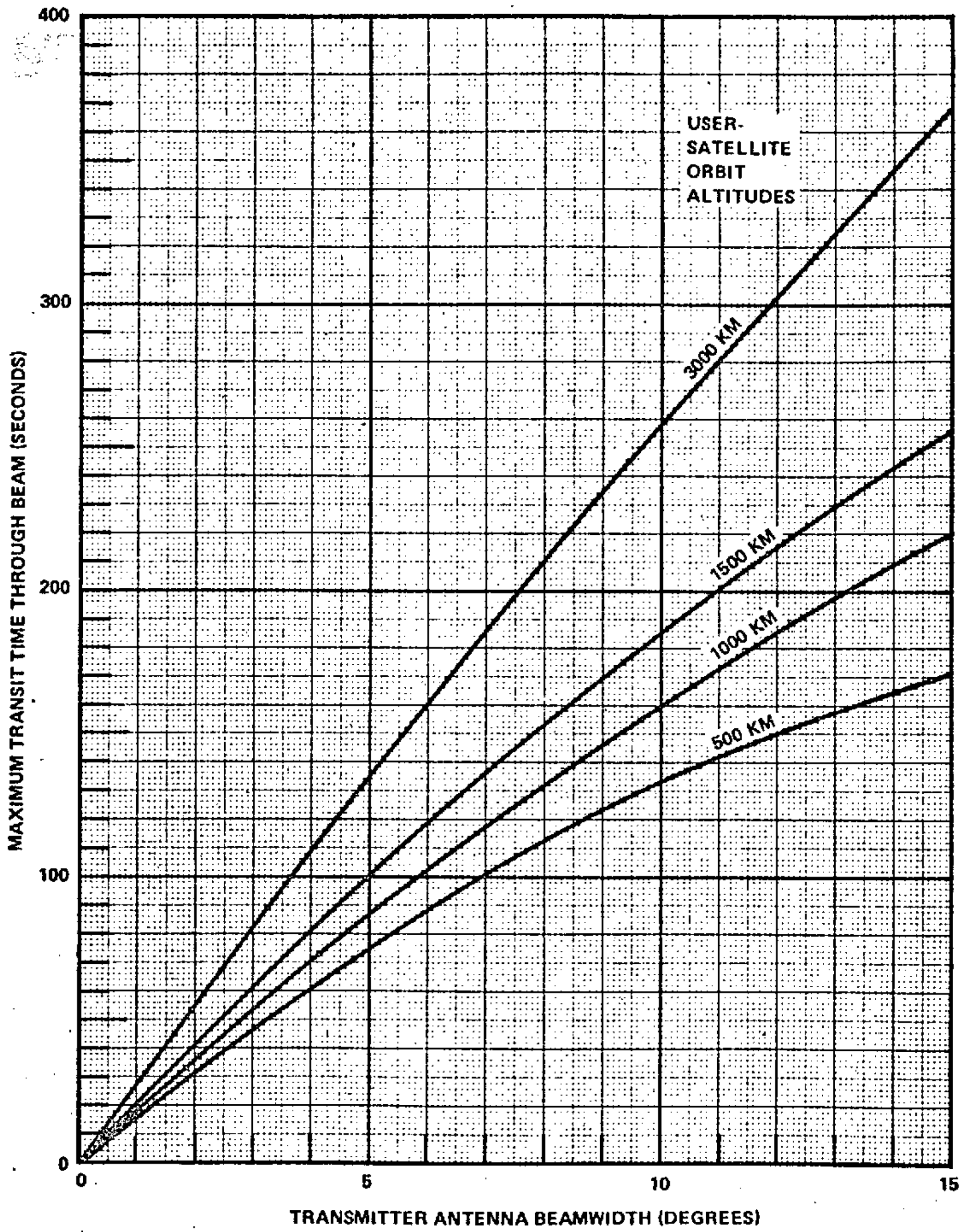

Figure 4-5. Theoretical Maximum Transit Time of Exemplary Satellites With a Microwave Radio-Relay Antenna Beam

- Continued.

evaluated together. Theoretically, the longest duration intersection would be for:

(1) A satellite in a direct equatorial orbit (that is, a zero-inclination orbit in the same direction as the earth rotation).

(2) A radio-relay antenna site on the equator and pointed either due east or west in azimuth.

This rather special case results, not only in the satellite passing along the major axis of the radio-relay beam, but also with the earth-rotation movement of the beam in the same direction as the satellite velocity vector.

For this maximum intersection-duration case, the time can be evaluated as a function of the radio-relay transmitter antenna beamwidth and the altitude of the circular equatorial orbit. Figure 4-5 gives these results. For instance, a radio-relay transmitter operating at 2.3 GHz with a 6-foot diameter antenna aperture would have a half-power beamwidth of about 5 degrees; (a relatively wide beam for this type of system). A satellite in a 1500-kilometer altitude orbit, with all of the described special conditions in effect, would remain in this radio-relay beam a maximum of 100 seconds.

The greatest majority of low and medium altitude satellites will not be in equatorial orbit but instead will be operated with considerable inclination. Furthermore, although there are more radio-relay lines operating in generally east-west

- Continued.

directions than in north-south directions, their individual beam pointing directions are widely distributed in azimuth. Also, far fewer radio-relay lines are in operation in the equatorial regions of the earth than are in the highly commercial/ industrialized regions of the Northern Hemisphere temperate latitudes. Statistically, a particular satellite orbit revolution would rarely pass through the center of a radio-relay beam (note Figure 4-4). The probabalistic result is that typical transit times of satellites through such beams would be much less than the maximum times evaluated in Figure 4-5.

It does not appear that a rigorous statistical analysis of this phenomenom is warranted. A general conclusion can be drawn that, when intersection of a satellite path with a radio-relay beam occurs, the average transit time would be the order of tens of seconds and rarely over a minute in duration.

APPENDIX A.

INITIAL SURVEY OF RFI SOURCES IN 2-TO 2.3-GHz BAND

This appendix recapitulates a preliminary survey of RFI sources likely to be found in about the 2-to 2.3-GHz band, which were reported in:

> Project MAP Memo 4 -- Quick-Look Review of Potential S-band RFI Sources, 2 March 1973, ESL-3814

In response to guidance given to ESL, at the conclusion of their 16 February 1973 briefing at NASA, Goddard Space Flight Center, a quick review of potential RFI sources was made in two frequency bands from 2025 to 2120 and 2200 to 2300 MHz of current interest to the TDRSS Program. Three general sources of data were examined then:

a. International Telecommunication Union (ITU) frequency registrations.

b. Electromagnetic Compatibility Analysis Center (ECAC) unclassified listing of equipment installations, from their special sift tape DB-1149A.

c. Certain U.S. security-classified listings (EPL).

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Information derived from the latter were forwarded in Project MAP Memo 3 through an appropriate controlled communication channel. The following summary provides the highlights of preliminary findings from the ITU and partial ECAC data.

Although classified military electronics communications emitter systems are not included in this accounting, ECAC data (for essentially the U.S. and Canada) indicates substantial usage of these bands, primarily for point-to-point microwave relay communications. At least these transmitters dominate the utilization from the standpoint of duty cycle. They may be in use most if not all of the day, whereas, most other applications found are judged to be relatively sporadic in time usage. See Table A-1.

ITU registration listings were also reviewed, even though interpretation is more vague because they represent only a frequency allocation request rather than necessarily individual transmitter installations or operation. Nevertheless, they certainly indicate grossly the communications-type usage which are prevelant. Virtually all frequency allocations in these bands indicate merely "fixed station" service, implying point-to-point communications. In ITU Region 1 (Europe, Africa, and USSR), there were about 200 frequency allocations listed in the 2025-to 2120-MHz band and about 400 allocations in the 2200-to 2300-MHz band. In Region 3 (Asia except USSR, East Indies, Australia, and most of the South Pacific and Indian Ocean areas), there are listings for only about 40 frequencies in each of these two bands.

Table A-1. RF Usages Reported in North America

Type of Service/Function	Approximate Number of Transmitters
2025 to 2120 MHz band:	
Broadcast television (auxiliary)	226
Canadian point-to-point communications	135
U.S. point-to-point communications	99
NASA telemetry, etc.	40
Experimental research (mobile)	10
USAF space research (aircraft)	4
U.S. meteorological services	2
TOTAL	516
2200 to 2300 MHz band:	
Candian point-to-point communications	181
Telemetry: landbased	70
space vehicle	52
land mobile	48
airborne	43
Experimental research	31
Test and development (experimental)	28
Space research	19
Space tracking	15
Experimental (mobile)	12
Fixed stations	11
Special instrumentation	4
Point-to-point communications	3
Mobile communications (base)	3
U.S. armed forces point-to-point communications	3
Satellite instrumentation	2
TOTAL	525

APPENDIX A -- Continued.

Although ostensibly redundant to the ECAC data, ITU listings for their Region 2 (North and South America and the north Pacific area) indicate the frequency usage to be dominated by the U.S. and Canada, except for some 20 registrations in Argentina in the 2025-to 2120-MHz band and about 60 for the 2200-to 2300-MHz band, plus a smattering of other isolated uses in the Western Hemisphere.

The heaviest single system of users of this band for communications are the point-to-point radio relay lines in Canada, distributed in frequency throughout the 2000-to 2350-MHz band. In a number of U.S. states, there are block assignments of frequencies to "broadcast auxiliary, television" service, that can be either mobile or fixed, apparently used to relay live television sequences from mobile or outlying camera sites to a central station. These 17-MHz wide frequency blocks are bounded at 2008, 2025, 2042, 2059, 2076, 2093, and 2110 MHz.

A gross analysis was made of the likely incidence of transmitter main-beam intersections from microwave relay installations in North America with either of two planned TDRSS geo-synchronous locations. From geometric beamwidth considerations alone, there should be main-beam coupling from less than 0.5 percent of the fixed directive antennas in North America. A cursory comparison of the locations and azimuths of the ECAC unclassified installation listings appears to confirm this statistic.

APPENDIX A -- Continued.

From the quick-look examination, it appears likely that adequate bandwidths for TDRSS channels should be available devoid of main-beam RFI from fixed-station communication systems. The more significant problem appears to be RFI from radars, notably in the USSR and some of the Eastern European allies.

Considering a nominal case of a 1-megawatt transmitter-power radar, with its antenna scanning or pointed in an arbitrary direction, there would be conservatively a probability of 0.5 that the radar ERP would exceed 80 dBm in the direction of a TDRSS in field of view above the horizon. The free-space loss to synchronous altitude varies from about 189 to 192 dB, as a function of both specific RF between 2025 and 2300 MHz and various radar locations on the earth relative to a TDRSS position. Using 190-dB space loss, simply, there would be a power level of -110 dBm at the TDRSS from this nominal radar pulse, plus the gain of the TDRSS antenna in use. (This assumes that the TDRSS receiver bandpass is generally as wide as the radar pulse spectrum.) Probabilistically, we pose that half the pulses from the many such radars in view would be lower power, but the other half, higher, sometimes much higher, in power.

With TDRSS antenna gain included, the power received from such a pulse would be above the threshold of RFI tolerance. Therefore, the problem appears to center on determining how many such pulses would be transmitted within the field of view in a unit of time and their aggregate pulse duration. The statistics of this summation would indicate the average proportion of time that TDRSS communication could take place in a given radar pulse environment.

how can knowledge of location of RFI sources be inputted into the AGIPA as a priori info. !